APBF-DEC

Quarterly Update

**Advanced Petroleum-Based Fuels–
Diesel Emissions Control (APBF-DEC) Project**

#8, Winter 2003

BACKGROUND

The APBF-DEC is an industry/government project to identify and evaluate (1) the optimal combinations of low-sulfur diesel fuels, lubricants, diesel engines, and emission control systems to meet projected emission standards for the 2000 to 2010 time period, while maintaining improvement in engine efficiency and durability and (2) properties of fuels and vehicle systems that could lead to even lower emissions beyond 2010.

Sulfur in the fuel is known to interfere with the functioning of most emission control technologies and has been implicated as a possible factor in the formation of ultrafine particulate matter (PM). A systems approach is being used, i.e., simultaneously investigating fuels, lubricants, engines, and emission control systems.

A government/industry steering committee and working groups are guiding the APBF-DEC project. Funding for the project has been budgeted at $33 million and is being provided by federal and state government agencies, trade associations, and private industry. Representatives from these and other agencies, trade and professional associations, national laboratories and private sector companies serve on the 20-member APBF-DEC Steering Committee and its working groups.

The project is managed by DOE's National Renewable Energy Laboratory (NREL). Information about the APBF-DEC project is posted at: http://www.ott.doe.-gov/apbf.shtml.

APBF-DEC is the successor to the Diesel Emissions Control-Sulfur Effects (DECSE) project. DECSE publications and technical reports are available at: http://www.ott.-doe.gov/decse/.

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Five Test Projects Complete Initial Tasks, Move to Next Phases Using Different Systems*

Five test projects have been underway since the spring of 2001 at laboratories across the country to determine the best combinations of low-sulfur (S) diesel fuels, lubricants, diesel engines, and emission control systems to meet projected emission standards for the 2000 to 2010 time period. Also being studied are properties of fuels and vehicle systems that could lead to even lower emissions beyond 2010.

The tests are part of the Advanced Petroleum-Based Fuels—Diesel Emissions Control (APBF-DEC) project. The five test projects are evaluating:

- Selective catalytic reduction/diesel particle filter (SCR/DPF) technologies, fuels, and engines
- Nitrogen oxides (NO_x) adsorber catalyst/DPF technologies, fuels, and engines for passenger cars, light-duty trucks/SUVs, and heavy-duty applications (3 projects) and
- Lubricant formulations that may affect the performance and durability of advanced diesel emission control systems.

Initial tasks for the SCR and NO_x adsorber projects were to develop the test cells and install test engines, optimize the systems to reduce emissions, determine the effects of various S levels in diesel fuel on regulated and unregulated emissions, and conduct emission control systems durability tests. The lubricants project began by measuring engine-out emissions using a variety of oil formulations.

The APBF-DEC project responds to the need for both light- and heavy-duty vehicles to meet the imminent stricter emission control standards. Between 2004 and 2009, lower emission standards will be phased in for passenger cars and light-duty trucks up to 10,000 pounds gross vehicle weight rating (GVWR). These are "fuel neutral" standards, and for diesel-powered vehicles to comply, catalytic emission control systems will most likely be required. The U.S. Environmental Protection Agency (EPA) has also set new emission standards for heavy-duty engines, which will be phased in between 2007-2010, and has mandated drastic reductions in the S content of on-highway diesel fuel by 2006. These standards (for emissions of both particulate matter [PM] and NO_x) will, for the first time, require catalytic emission control systems on heavy-duty vehicles.

This Quarterly Update is excerpted from the APBF-DEC Annual Progress Report, FY 2002, which will be available in its entirety at the following Web site:* ***http://www.ott.doe.gov/apbf.shmtl***.**

Selective Catalytic Reduction/Diesel Particle Filter (SCR/DPF) Project

Test Bed: Caterpillar C-12 engine, a heavy-duty engine, model year 2000
Testing Laboratory: Southwest Research Institute (SwRI), San Antonio, TX
Technical Monitor: Ralph McGill, Oak Ridge National Laboratory (ORNL)

Technologies. The SCR/DPF project is conducting tests using a 12-liter Caterpillar engine, which has a displacement of 12 liters, six cylinders, 24 valves, a turbocharger, and intercooler. The engine without modifications exhausts approximately 3.5 grams/brake horsepower-hour (g/bhp-hr) of NO_x and 0.07 g/bhp-hr of PM with D2 diesel fuel and on the hot cycle federal test procedure (FTP) transient test. A low-pressure-loop exhaust gas recirculation (EGR) system is added to the engine emission control system to reduce the levels of engine-out NO_x. Two types of SCR catalysts and DPFs are being used.

Experimental Design. The emission control systems are added one by one to the engine, and controls are optimized for lowest emissions while retaining fuel economy and engine performance. This is done in separate, consecutive efforts with systems A and B. Once the system is optimized, it is evaluated for emissions with different fuels—3-, 8-, 15-, and 30-ppm DECSE S fuel and a low-sulfur refinery fuel. Regulated and unregulated emissions are measured.

Test Methods. During the first 200 hours of testing with SCR/DPF System A, the system was optimized and tests were conducted to measure emissions and to determine whether the system can meet 2007 emission regulations. These regulations will limit emissions to 0.20 g/bhp-hr for NO_x and 0.01 g/bhp-hr for heavy-duty engines. After emissions optimization, the system is transferred to the durability cell for 6,000 hours of aging in three stages of 2,000 hours each. Emissions tests are performed at the end of each stage.

Interim Results. The test engine had transient NO_x/PM emissions of 3.5/0.07 g/bhp-hr. The low-pressure-loop EGR system, with a DPF, was calibrated to yield more than a 50% re-duction in NO_x and a 90% reduction in PM when using 3-ppm S fuel and a low-pressure loop EGR, in comparison to engine-out results with 350-ppm S fuel. All low-sulfur fuels (e.g., 3-, 8-, 15-, and 30-ppm plus the low-sulfur refinery fuel) using a fresh System A produced emissions close to but not below the 2007 regulatory emission standards for NO_x and below the PM standards for both the steady-state and transient emission tests.

SCR/DPF. The selective catalytic reduction technology (SCR) is an emissions reduction technology that—combined with a diesel particle filter (DPF), advanced fuel formulations and engine technologies—can reduce NO_x and PM emissions. Two different SCR/ DPF systems are being evaluated.

The purposes of this test are to demonstrate the low diesel emissions possible by using advanced fuels, engines, and SCR/DPF technologies; evaluate the sensitivities of emission controls to fuel variables, determine regulated and unregulated emissions with and without emission controls, and examine the emission control system's durability.

Three NO_x Adsorber/Diesel Particle Filter (DPF) Projects

Three laboratories are testing NO_x adsorber catalyst/DPF technologies on three different vehicle/engine platforms to assess their emission reduction performance and to evaluate the effects of fuel sulfur on the durability of the emission control components. The three laboratories are conducting similar tasks to develop and refine regeneration and desulfurization strategies, measure regulated and unregulated emissions, and evaluate each system's performance with varying fuel sulfur levels over transient and steady-state cycles. The projects are testing the integration of selected engines/vehicles, emission control systems (ECS), and optimized engine management systems. The goal is to enable these systems to operate effectively on 8- and 15-ppm S fuels and meet federal emission standards that will go into effect in 2007.

Experimental Design. The experimental designs for the three NO_x adsorber projects are fairly similar. Each involves aging and periodic evaluations of one or two ECS configurations with a combination of four fuel S levels. Tests are being conducted using 0.6-, 8-, 15-, and 30-ppm S fuels, but the focus will be on the comparison between 8- and 15-ppm S fuels. Baseline engine-out emissions for 8- and 15-ppm S fuel will also be included as part of this testing. At limited points during the aging, evaluations will occur using the BP15 fuel. At these points, detailed emission sampling will take place and include the measurement of unregulated and toxic emissions. The testing will include emission evaluations over appropriate test cycles and durability testing.

NO_x Adsorber/DPF. The NO_x adsorber catalyst is a flow-through exhaust emissions control device with the potential to significantly reduce nitrogen oxides (NO_x) emissions in the exhaust from diesel engines. When combined with a DPF, the system also can oxidize the diesel particulate matter (PM), hydrocarbon (HC) and other unregulated emissions.

The purpose of the three separate platforms is to demonstrate the potential of low-sulfur fuel to achieve stringent emission reductions from diesel engines of different power, using a system the includes the engine, fuel, NO_x adsorber, DPF, and thermal management technologies.

Passenger Car NO_x Adsorber/Diesel Particle Filter (DPF)

Test Bed: Audi A4 Avant with a 1.9 liter (L) TDI engine
Testing Laboratory: FEV Engine Technology, Inc., Auburn Hills, MI
Technical Monitor: Matthew Thornton, National Renewable Energy Laboratory (NREL)

Technologies. Evaluations are being conducted on two prototype 1.9 liter (L) TDI engines installed in the engine test cell. The prototype has advanced engine controls and advanced ECS technologies (two different ECSs will be evaluated for this project). The engine specifications are: in-line four cylinders, displacement of 1.9 liters, rated power of 100 KW @ 4,000 revolutions per minute (rpm), a turbocharger, a common rail fuel injection system, and four valves per cylinder. Limited testing will also be conducted on the chassis with the Audi A4 Avant with the same prototype 1.9L engine.

Test Methods. The ECSs will be aged in the engine test cell where emission evaluations will also occur. Limited evaluations will occur with the ECSs installed on the vehicle in order to validate the engine test cell results. Analyzers will be strategically placed before and after the individual ECS components to gain a clear understanding of the gaseous emissions going into and coming out of each ECS component. All of the detailed gaseous and PM emissions will be collected strictly in the engine test cell using a constant volume sampling (CVS) method in a dilution tunnel.

Interim Results. Accomplishments during FY 2002 included acquiring and preparing all the required hardware, assembling the technologies (e.g., the prototype engines), and receiving the first set of NO_x adsorber catalysts and DPFs. The ECS for the test cell was degreened and will be used for the base calibration work and to measure the storage capacity of the NO_x adsorber catalyst. The EGR strategy has been optimized to reduce engine-out NOx emissions to approximately 0.4 g/mile over the FTP drive cycle with minimal increased fuel consumption. The rapid warmup strategy has also been defined. During FY 2003, the regeneration and desulfurization strategies will be defined and the core aging and evaluation testing will begin for both ECS configurations using 8-ppm and 15-ppm S fuel. This will include aging of one system for over 1,000 hours.

Medium-Duty Truck/SUV NO_x Adsorber/Diesel Particle Filter (DPF)

Test Bed: 2500 series Chevrolet Silverado, with a Duramax 6.6L engine
Testing Laboratory: SwRI, San Antonio, TX
Technical Monitor: Matthew Thornton, NREL

Technologies. Two 2002 Duramax 6.6L engines with a rated horsepower of 300, turbocharger, direct fuel injection, and EGR are being used in this project. The test vehicle is a 2002 model year Chevrolet Silverado. The major advantage of the Silverado is its underbody geometry, which allows space for additional emission control components. The emission components to be added for the tests are a NO_x adsorber and a catalyzed DPF, which will be integrated with an exhaust supplemental fuel injection to provide the systems with sufficient reductant.

Test Methods. A dual leg ECS will be aged in the engine test cell with all of the emission evaluations also occurring in the test cell. Analyzers will be strategically placed before and after the individual components to gain a clear understanding of the gaseous emissions going into and coming out of each component. All of the detailed gaseous and PM emissions will be collected in the engine test cell, using a dilution tunnel with CVS.

Interim Results. The Duramax 6.6L engine has been installed in the engine test cell where all emission evaluations will be performed. Initial tests were conducted over the light-duty test procedures in the fall to provide engine-out data needed to properly size the components in the ECS. Extensive work on thermal management/generation and reducing engine and emission levels has been completed. This has included re-mapping the EGR system, introducing intake throttling, and the development and integration of a diesel fuel burner.

Heavy-Duty NO_x Adsorber/Diesel Particle Filter (DPF)

Test Bed: 15L Cummins ISX, DOHC engine
Testing Laboratory: Ricardo, Inc., Burr Ridge, IL
Technical Monitor: Shawn Whitacre, NREL

Technologies. Two types of control systems were initially evaluated—single-leg NO_x adsorber catalyst system and twin-bed (with bypass) NO_x adsorber catalyst system. Regeneration and desulfurization strategies are being developed to enable the system to meet emission targets while minimizing the fuel economy penalty associated with their operation. The test cell was set-up and hardware was acquired and installed. The test engine is a Cummins ISX diesel, 15-liter engine rated at 475 horsepower, using dual overhead camshafts, four valves per cylinder, central electronic unit injectors, variable geometry turbocharger, cooled EGR, and electronic controls. The base engine emissions are approximately 2.5 g/bhp-hr for NO_x and 0.1 g/bhp-hr for PM.

Test Methods. The test objectives are to evaluate the effects of fuel sulfur levels on the engine and emission control system's performance, emissions and fuel economy, and the durability of the catalyst. Engine control systems are being designed to permit regeneration and desulfurization over heavy-duty transient and under steady-state conditions. Durability effects on the engine may need to be examined further.

Interim Results. Initial preliminary results indicate that the fresh NO_x adsorber catalyst can reduce NO_x emissions by 85% and, at peak efficiency, by up to 98%. Other preliminary emission results under transient conditions have been encouraging, with the composite federal test procedure (FTP) results falling below the 0.20 g/bhp-hr. These tests were conducted without a clean-up catalyst so HC and CO emissions should be lower when the full system is used.

Lubricants

Test Bed: International T444E, 7.3L engine, with retrofits
Testing Laboratory: Automotive Testing Laboratories, East Liberty, OH
Technical Monitor: Shawn Whitacre, NREL

The APBF-DEC lubricants project is being conducted in two phases in parallel with the four engine hardware technology projects. The role of the lubricants project is to determine which, if any, lubricant-derived components in engine-out emissions are detrimental to the performance or durability of vehicle emission control systems. These devices are sufficiently sulfur sensitive and their durability requirements—particularly in heavy-duty engines— are so extensive that reducing the fuel S level may not be enough, if other sources of catalyst poisons remain. For example, the sulfur and ash in lubricant oils may poison or interfere with the NO_x adsorber catalyst or plug the DPF.

Lubricants. Testing of lubricant formulations is being conducted to determine which, if any, lubricant-derived components in the emissions are detrimental to the performance or durability of the emission control systems (ECS). The test engine is installed on a dynamometer combining a double-ended GE DC-electric brake (200hp) with a Go-Power DT-2000 water brake (800hp), which provides precise control and high torque/power absorption capability on a single in-line assembly.

Experimental Design. Phase I concentrated on acquiring and analyzing emissions data to determine how lubricant-derived components affect engine-out emissions and which components have the potential to affect the performance and durability of vehicle emission control systems. Analyses of 57 lubricant evaluations were conducted in back-to-back runs. Tests of the oil/additives combinations were performed at the beginning and end of the tests, as well as before and after aging.

Technologies. The engine is direct-injected, electronically controlled, turbocharged and aftercooled, with a displacement of 7.3L in a V8 configuration with two valves per cylinder. It is equipped with a Siemens electronic control unit and hydraulically actuated electronic unit injectors. Additional hardware was installed to allow EGR and closed crankcase ventilation (CCV).

Test Methods. Testing included evaluations of a matrix of additives and base oils selected from each of the four major base oil groups—as defined by the American Petroleum Institute (API). The additive packages were provided by five different suppliers and were selected to represent a range of current and future additive technologies. One reference oil was selected and tested periodically to characterize drift in the measurement system or engine performance.

Interim Results—Phase I. Mass balances were conducted for each of the critical parameters in oils. Predicted emission rates for each species were estimated based upon fuel and lubricant properties and fuel and lubricant consumption rates. Summaries of each species are:

- Calcium emission rates are directly correlated with the concentration of calcium in the oil, independent of any given additive formulation.
- Zinc emissions are directly correlated to the concentration in the tested formulation with 43% estimated recovery.
- Phosphorous recovery is consistent with predictions (90%) and highly correlated with the phosphorus concentration of the oil—except in one of the oils.
- Sulfur's impact on the durability of NO_x adsorber catalysts required that scrutiny be given to lubricant-derived sulfur. SO_2 emissions for the various additive and basestock combinations were tested. Additives A-F were tested in each of the four basestock groups while additives G-L (and the reference oil R) were tested exclusively in the Group II stock. Of the four basestocks tested, only the Group I stock had significant sulfur content (approximately 5,000-ppm S).